

# Unparticle Physics in DIS

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## Abstract

The unparticle stuff scenario related to the nontrivial IR fixed point in 4D-conformal field theory is recently suggested by Georgi. We illustrate its physical effects in Deep Inelastic Scattering (DIS) process. A possible signal of unparticle related to parity violation asymmetry in DIS is investigated. It is found out that the behavior of this parity violation signal is sensitive to the value of the scale dimension  $d_{\mathcal{U}}$  of unparticle.

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## I. INTRODUCTION

It is well-known that conformal symmetry plays important role in both critical phenomena and the superstring theory. Nevertheless, in particle physics in four dimensional space-time dimension, conformal symmetry is broken by the masses of the particles explicitly, and even though there is conformal symmetry classically, this symmetry would be broken by the renormalization effect. However, at high energy scale, there could exist stuff with nontrivial scale invariance in the infrared (such as the Banks-Zaks field[1]), which is recently suggested by Howard Georgi as a component of the beyond standard model (SM) physics above the TeV scale[2].

Since unparticle stuff is completely new to us, and we don't have a picture of what the unparticle looks like, and the theories with nontrivial IR fixed point is very complex, Georgi have used the method of the low energy effective field theory to study the unparticle stuff production[2] and the peculiar virtual effects in high energy processes[3]. Moreover, the unparticle production in  $e^+e^- \rightarrow \gamma\mathcal{U}$ , mono-jet production, the virtual effects of the unparticle in the Drell-Yan process and the muon anomaly have been investigated[4], and the fermionic unparticles are introduced as well[5]. Unparticle physics have very interesting and rich phenomenological consequences. In this paper, we shall explore the phenomenological consequences of unparticle in deep inelastic scattering (DIS) in the framework of the effective field theory.

We follow closely the scenario studied in[2, 3]. The fields of the theory with nontrivial IR fixed point are denoted as  $\mathcal{BZ}$  fields, and the SM fields and the  $\mathcal{BZ}$  fields interact through the exchanges of particles with a high mass scale  $M_{\mathcal{U}}$ . Thus, below the high scale  $M_{\mathcal{U}}$ , the effective nonrenormalizable couplings between them are follows,

$$\frac{1}{M_{\mathcal{U}}^k} \mathcal{O}_{SM} \mathcal{O}_{\mathcal{BZ}}, \quad (1)$$

where  $\mathcal{O}_{SM}$  and  $\mathcal{O}_{\mathcal{BZ}}$  are respectively the local operators built up of SM fields and the  $\mathcal{BZ}$  fields. Furthermore, below the scale  $\Lambda_{\mathcal{U}}$  where the scale invariance in the  $\mathcal{BZ}$  sector emerges, the  $\mathcal{BZ}$  operator  $\mathcal{O}_{\mathcal{BZ}}$  is matched onto the unparticle operator  $\mathcal{O}_{\mathcal{U}}$ , and Eq.(1) is matched onto the effective interactions between the SM fields and the unparticle fields of the following form,

$$\frac{C_{\mathcal{U}} \Lambda_{\mathcal{U}}^{d_{\mathcal{BZ}} - d_{\mathcal{U}}}}{M_{\mathcal{U}}^k} \mathcal{O}_{SM} \mathcal{O}_{\mathcal{U}} \quad (2)$$

where  $d_{BZ}$  and  $d_U$  are respectively the scale dimensions of the local operators  $\mathcal{O}_{BZ}$  and  $\mathcal{O}_U$ , and  $C_U$  is the coefficient function which is determined by the matching processes.

The following effective interactions of interesting phenomenologies have been introduced in [2, 3],

$$\begin{aligned} & \frac{C'_{SU}\Lambda_U^{k-d_U}}{M_U^k} G_{\mu\nu} G^{\mu\nu} \mathcal{O}_U, \quad \frac{C_{TU}\Lambda_U^{k-d_U}}{M_U^k} G_{\mu\lambda} G_\nu^\lambda \mathcal{O}_U^{\mu\nu}, \quad \frac{\Lambda_U^{k+1-d_U}}{M_U^k} \bar{f} \gamma_\mu (C_{VU} + C_{AU} \gamma_5) f \mathcal{O}_U^\mu \\ & \frac{\Lambda_U^{k+1-d_U}}{M_U^k} \bar{f} (C_{SU} + i C_{PU} \gamma_5) f \mathcal{O}_U \end{aligned} \quad (3)$$

where  $G_{\mu\nu}$  is the gluon field strength,  $f$  denotes the SM fermion fields, and universal coupling between the unparticles and the SM fermionic fields has been assumed.  $\mathcal{O}_U$ ,  $\mathcal{O}_U^\mu$  and  $\mathcal{O}_U^{\mu\nu}$  are respectively the scalar, vector and tensor unparticle operators. They are taken to be hermitian and the latter two operators are assumed to be transverse. Naively  $C_{VU}$ ,  $C_{AU}$ ,  $C_{SU}$  and  $C_{PU}$  should be of the same order. The interactions in Eq.(3) are generally weak, moreover the first two couplings in Eq.(3) are suppressed by  $\frac{1}{\Lambda_U}$  in comparison with the latter two, so the latter two effective interactions is dominant in the DIS processes with virtual unparticle exchange. And we should work to the lowest order in the small couplings of unparticle fields with the SM fields in the effective theory. Similar to Ref.[3] the following dimensionless coefficients are introduced for convenience,

$$c_{VU} = \frac{C_{VU}\Lambda_U^{k+1-d_U}}{M_U^k M_Z^{1-d_U}}, \quad c_{AU} = \frac{C_{AU}\Lambda_U^{k+1-d_U}}{M_U^k M_Z^{1-d_U}}, \quad c_{SU} = \frac{C_{SU}\Lambda_U^{k+1-d_U}}{M_U^k M_Z^{1-d_U}}, \quad c_{PU} = \frac{C_{PU}\Lambda_U^{k+1-d_U}}{M_U^k M_Z^{1-d_U}} \quad (4)$$

Following Ref.[2, 3], by conformal symmetry, we have,

$$\langle 0 | \mathcal{O}^\mu(0) | P \rangle \langle P | \mathcal{O}^\nu(0) | 0 \rangle = A_{d_U} \theta(P^0) \theta(P^2) (-g^{\mu\nu} + \frac{P^\mu P^\nu}{P^2}) (P^2)^{d_U-2} \quad (5)$$

where

$$A_{d_U} = \frac{16\pi^{5/2}}{(2\pi)^{2d_U}} \frac{\Gamma(d_U + 1/2)}{\Gamma(d_U - 1)\Gamma(2d_U)} \quad (6)$$

which is normalized with respect to the phase space of  $d_U$  massless particles, and the two-point correlation function of the unparticle operator  $\mathcal{O}^\mu$  can be obtained as follows,

$$\int d^4x e^{iP \cdot x} \langle 0 | T(\mathcal{O}^\mu(x) \mathcal{O}^\nu(0)) | 0 \rangle = \frac{i A_{d_U}}{2 \sin(d_U \pi)} \frac{-g^{\mu\nu} + P^\mu P^\nu / P^2}{(-P^2 - i\epsilon)^{2-d_U}} \quad (7)$$

Similarly,

$$\int d^4x e^{iP \cdot x} \langle 0 | T(\mathcal{O}(x) \mathcal{O}(0)) | 0 \rangle = \frac{i A_{d_U}}{2 \sin(d_U \pi)} \frac{1}{(-P^2 - i\epsilon)^{2-d_U}} \quad (8)$$

The above propagator factor has been obtained independently by Georgi[3] and Cheung *et al.*,[4].

## II. DIS PROCESSES AND UNPARTICLE

Since the effective interaction between the unparticle fields and the SM fermions in Eq.(3) is flavor-conserving, which is consistent with the suppressed flavor changing neutral current (FCNC) transitions, the unparticle will only affect the neutral current ( $\gamma$  and  $Z$ ) exchange DIS processes  $\ell(\nu)N \rightarrow \ell(\nu)X$ , which is shown in Fig.1. For the charged lepton scattering  $\ell N \rightarrow \ell X$ , the differential scattering cross section is,

$$\frac{d^2\sigma^\ell}{dx dQ^2} = \frac{4\pi\alpha^2}{xQ^4} [xy^2 F_1^\ell + (1-y)F_2^\ell + y(1-\frac{1}{2}y)x F_3^\ell] \quad (9)$$

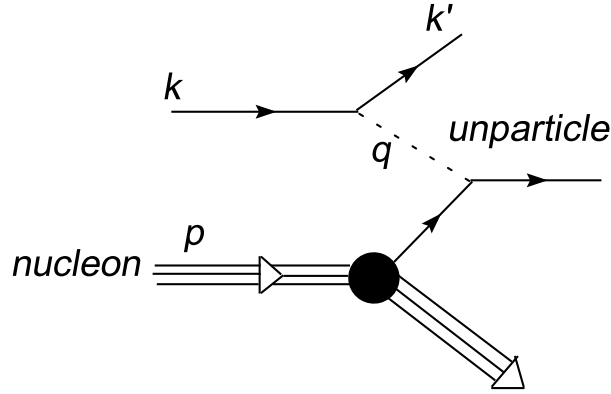


FIG. 1: Deep inelastic scattering with virtual unparticle exchange

where  $F_i^\ell(x, Q^2)$  ( $i=1,2,3$ ) is the structure functions which measure the structure of the target, and

$$\begin{aligned} F_1^\ell(x, Q^2) &= \sum_q [q(x) + \bar{q}(x)] B_q^\ell(Q^2) \\ F_2^\ell(x, Q^2) &= \sum_q x [q(x) + \bar{q}(x)] C_q^\ell(Q^2) \\ F_3^\ell(x, Q^2) &= \sum_q [q(x) - \bar{q}(x)] D_q^\ell(Q^2) \end{aligned} \quad (10)$$

with

$$\begin{aligned} B_q^\ell(Q^2) &= \frac{Q_q^2}{2} + \frac{(V_q^2 + A_q^2)(V_\ell^2 + A_\ell^2)}{32 \sin^4 \theta_W \cos^4 \theta_W} P_Z^2 + \frac{(c_{VU}^2 + c_{AU}^2)^2}{32 \pi^2 \alpha^2 M_Z^{4(d_U-1)}} P_U^2 - \frac{Q_q V_q V_\ell}{4 \sin^2 \theta_W \cos^2 \theta_W} P_Z \\ &\quad - \frac{Q_q c_{VU}^2}{4 \pi \alpha M_Z^{2(d_U-1)}} P_U + \frac{(V_q c_{VU} - A_q c_{AU})(V_\ell c_{VU} - A_\ell c_{AU})}{16 \pi \alpha \sin^2 \theta_W \cos^2 \theta_W M_Z^{2(d_U-1)}} P_{UZ} \\ &\quad + \frac{(c_{SU}^2 - c_{PU}^2)^2}{64 \pi^2 \alpha^2 M_Z^{4(d_U-1)}} P_U^2 \end{aligned} \quad (11)$$

$$C_q^\ell(Q^2) = Q_q^2 + \frac{(V_q^2 + A_q^2)(V_\ell^2 + A_\ell^2)}{16 \sin^4 \theta_W \cos^4 \theta_W} P_Z^2 + \frac{(c_{VU}^2 + c_{AU}^2)^2}{16 \pi^2 \alpha^2 M_Z^{4(d_U-1)}} P_U^2 - \frac{Q_q V_q V_\ell}{2 \sin^2 \theta_W \cos^2 \theta_W} P_Z$$

$$- \frac{Q_q c_{VU}^2}{2 \pi \alpha M_Z^{2(d_U-1)}} P_U + \frac{(V_q c_{VU} - A_q c_{AU})(V_\ell c_{VU} - A_\ell c_{AU})}{8 \pi \alpha \sin^2 \theta_W \cos^2 \theta_W M_Z^{2(d_U-1)}} P_{UZ} \quad (12)$$

$$D_q^\ell(Q^2) = \frac{V_q V_\ell A_q A_\ell}{4 \sin^4 \theta_W \cos^4 \theta_W} P_Z^2 + \frac{c_{VU}^2 c_{AU}^2}{4 \pi^2 \alpha^2 M_Z^{4(d_U-1)}} P_U^2 - \frac{Q_q A_q A_\ell}{2 \sin^2 \theta_W \cos^2 \theta_W} P_Z$$

$$- \frac{Q_q c_{AU}^2}{2 \pi \alpha M_Z^{2(d_U-1)}} P_U + \frac{(V_q c_{AU} - A_q c_{VU})(V_\ell c_{AU} - A_\ell c_{VU})}{8 \pi \alpha \sin^2 \theta_W \cos^2 \theta_W M_Z^{2(d_U-1)}} P_{UZ} \quad (13)$$

$$P_Z = \frac{Q^2}{Q^2 + M_Z^2}, \quad P_U = \frac{A_{d_U}}{2 \sin(d_U \pi)} (Q^2)^{(d_U-1)}, \quad P_{UZ} = \frac{A_{d_U}}{2 \sin(d_U \pi)} \frac{(Q^2)^{d_U}}{Q^2 + M_Z^2} \quad (14)$$

In Eq.(11-13),  $\theta_W$  is the Weinberg angle  $\sin^2 \theta_W \simeq 0.23$ [6],  $M_Z$  is the mass of the  $Z^0$  gauge boson  $M_Z \simeq 91.19 \text{ GeV}$ [6], and  $V_f = T_{3f} - 2Q_f \sin^2 \theta_W$ ,  $A_f = T_{3f}$ , where  $Q_f$  is the electric charge of the fermion  $f$  in unit of the positron electric charge  $e$ .  $Q^2$ ,  $x$  and  $y$  are the standard deep inelastic variables, which are defined by:

$$Q^2 = -(k - k')^2 = 2k \cdot k', \quad x = \frac{Q^2}{2p \cdot (k - k')}, \quad y = \frac{p \cdot (k - k')}{p \cdot k} \quad (15)$$

The *Callan - Gross* relation  $F_2^\ell(x, Q^2) = 2xF_1^\ell(x, Q^2)$  is violated by the term  $\frac{(c_{SU}^2 - c_{PU}^2)^2}{64 \pi^2 \alpha^2 M_Z^{4(d_U-1)}} P_U^2$  in Eq.(11) at the present stage, and it will receive additional small corrections if we include the suppressed effective interactions between the unparticle and the gluon in Eq.(3). If we set  $c_{VU} = c_{AU} = c_{SU} = c_{PU} = 0$ , ( *i.e.*, if the unparticle stuff doesn't exist in the Nature) the differential cross section Eq.(9) coincides with the well-known results. When  $c_{iU} \neq 0$  ( $i=V, A, S, P$ ), the contributions to the structure functions  $F_i^\ell(x, Q^2)$  ( $i=1,2,3$ ) due to unparticle emerge. Since the coupling  $c_{VU}$ ,  $c_{AU}$ ,  $c_{SU}$  and  $c_{PU}$  are small, to the lowest nontrivial order, the corrections to the structure functions are the interference terms between the space-like vector unparticle exchange amplitudes and the standard model amplitudes, whereas the leading corrections to  $e^+e^- \rightarrow \mu^+\mu^-$  are the interference terms between the time-like vector unparticle exchange amplitudes and the standard model amplitudes[3].

For the neutrino scattering  $\nu N \rightarrow \nu X$ , the corresponding differential scattering cross section is,

$$\frac{d^2 \sigma^\nu}{dx dQ^2} = \frac{G_F^2}{2\pi x} \left( \frac{M_Z^2}{Q^2 + M_Z^2} \right)^2 [xy^2 F_1^\nu + (1-y)F_2^\nu + y(1 - \frac{1}{2}y)x F_3^\nu] \quad (16)$$

the structure functions  $F_i^\nu(x, Q^2)$  ( $i=1,2,3$ ) are as follows,

$$F_1(x, Q^2) = \sum_q [q(x) + \bar{q}(x)] B_q^\nu(Q^2)$$

$$\begin{aligned}
F_2^\nu(x, Q^2) &= \sum_q x[q(x) + \bar{q}(x)]C_q^\nu(Q^2) \\
F_3^\nu(x, Q^2) &= \sum_q [q(x) - \bar{q}(x)]D_q^\nu(Q^2)
\end{aligned} \tag{17}$$

with

$$\begin{aligned}
B_q^\nu(Q^2) &= \frac{V_q^2 + A_q^2}{2} + \frac{(c_{VU}^2 + c_{AU}^2)^2}{2M_Z^{4d_U} G_F^2} R_{UZ}^2 + \frac{(V_q c_{VU} - A_q c_{AU})(c_{VU} - c_{AU})}{\sqrt{2} M_Z^{2d_U} G_F} R_{UZ} \\
&\quad + \frac{(c_{SU}^2 - c_{PU}^2)^2}{4M_Z^{4d_U} G_F^2} R_{UZ}^2
\end{aligned} \tag{18}$$

$$C_q^\nu(Q^2) = V_q^2 + A_q^2 + \frac{(c_{VU}^2 + c_{AU}^2)^2}{M_Z^{4d_U} G_F^2} R_{UZ}^2 + \frac{\sqrt{2} (V_q c_{VU} - A_q c_{AU})(c_{VU} - c_{AU})}{M_Z^{2d_U} G_F} R_{UZ} \tag{19}$$

$$D_q^\nu(Q^2) = 2V_q A_q + \frac{4c_{VU}^2 c_{AU}^2}{M_Z^{4d_U} G_F^2} R_{UZ}^2 - \frac{\sqrt{2} (V_q c_{AU} - A_q c_{VU})(c_{VU} - c_{AU})}{M_Z^{2d_U} G_F} R_{UZ} \tag{20}$$

$$R_{UZ} = \frac{A_{d_U}}{2 \sin(d_U \pi)} (Q^2)^{d_U-2} (Q^2 + M_Z^2) \tag{21}$$

where  $G_F$  is the Fermi constant  $G_F \simeq 1.166 \times 10^{-5} \text{GeV}^2$ [6]. If we set  $c_{VU} = c_{AU} = c_{SU} = c_{PU} = 0$ , the differential cross section reduces to the well-known result, and the *Callan – Gross* relation  $F_2^\nu(x, Q^2) = 2xF_1^\nu(x, Q^2)$  is violated by the  $\frac{(c_{SU}^2 - c_{PU}^2)^2}{4M_Z^{4d_U} G_F^2} R_{UZ}^2$  term in Eq.(18).

In order to see how the unparticle affects the structure functions, it is instructive to first assume  $c_{VU} = 0$ , then there isn't interference between the unparticle exchange amplitudes and the photon exchange amplitudes. We can easily see that dominant correction is proportional to  $c_{AU}^2$ , here we omit the high order terms which contain  $c_{AU}^4$ ,  $c_{SU}^4$  and  $c_{PU}^4$ , and in this case the changes of the functions  $B_q^\ell(Q^2)$ ,  $C_q^\ell(Q^2)$ ,  $D_q^\ell(Q^2)$ ,  $B_q^\nu(Q^2)$ ,  $C_q^\nu(Q^2)$  and  $D_q^\nu(Q^2)$  caused by unparticle exchanges are respectively the following:

$$\begin{aligned}
2\Delta B_q^\ell(Q^2)/c_{AU}^2 &\approx \Delta C_q^\ell(Q^2)/c_{AU}^2 \approx \frac{A_q A_\ell}{16\pi\alpha M_Z^{2(d_U-1)} \sin^2 \theta_W \cos^2 \theta_W} \frac{A_{d_U}}{\sin(d_U \pi)} \frac{(Q^2)^{d_U}}{Q^2 + M_Z^2} \\
\Delta D_q^\ell(Q^2)/c_{AU}^2 &\approx -\frac{Q_q}{4\pi\alpha M_Z^{2(d_U-1)} \sin(d_U \pi)} \frac{A_{d_U}}{(Q^2)^{(d_U-1)}} + \frac{V_q V_\ell}{16\pi\alpha \sin^2 \theta_W \cos^2 \theta_W M_Z^{2(d_U-1)}} \\
&\quad \times \frac{A_{d_U}}{\sin(d_U \pi)} \frac{(Q^2)^{d_U}}{Q^2 + M_Z^2} \\
2\Delta B_q^\nu(Q^2)/c_{AU}^2 &\approx \Delta C_q^\nu(Q^2)/c_{AU}^2 \approx \frac{A_q}{\sqrt{2} M_Z^{2d_U} G_F} \frac{A_{d_U}}{\sin(d_U \pi)} (Q^2)^{(d_U-2)} (Q^2 + M_Z^2) \\
\Delta D_q^\nu(Q^2)/c_{AU}^2 &\approx \frac{V_q}{A_q} (\Delta C_q^\nu(Q^2)/c_{AU}^2)
\end{aligned} \tag{22}$$

As a illustration the leading order unparticle corrections  $\Delta C_u^e(Q^2)/c_{AU}^2$ ,  $\Delta D_u^e(Q^2)/c_{AU}^2$  and  $\Delta C_u^\nu(Q^2)/c_{AU}^2$  for various  $d_U$  are respectively shown in Fig.2-Fig.4. Since  $\Delta D_q^\nu(Q^2)/c_{AU}^2$

is proportional to  $\Delta C_q^\nu(Q^2)/c_{A\mathcal{U}}^2$ , we have not shown the profile of  $\Delta D_q^\nu(Q^2)/c_{A\mathcal{U}}^2$ . For  $1 < d_{\mathcal{U}} < 2$ ,  $\sin(d_{\mathcal{U}}\pi)$  is negative, so  $\Delta C_u^\nu(Q^2)/c_{A\mathcal{U}}^2$  shown in Fig.4 is negative, while  $\Delta C_u^e(Q^2)/c_{A\mathcal{U}}^2$  and  $\Delta D_u^e(Q^2)/c_{A\mathcal{U}}^2$  are positive. We note that  $\Delta C_u^e(Q^2)/c_{A\mathcal{U}}^2$  and  $\Delta D_u^e(Q^2)/c_{A\mathcal{U}}^2$  increase with the increase of  $Q^2$ , however,  $|\Delta C_u^\nu(Q^2)/c_{A\mathcal{U}}^2|$  firstly decrease, then begin to increase at  $Q^2 = \frac{2-d_{\mathcal{U}}}{d_{\mathcal{U}}-1} M_Z^2$ .

After discussion on the pure axial vector unparticle couplings, we now turn to the pure vector coupling case, *i.e.*,  $c_{V\mathcal{U}}$  is nonzero and  $c_{A\mathcal{U}} = 0$ . The leading order corrections  $\Delta B_q^\ell(Q^2)/c_{V\mathcal{U}}^2$ ,  $\Delta C_q^\ell(Q^2)/c_{V\mathcal{U}}^2$ ,  $\Delta D_q^\ell(Q^2)/c_{V\mathcal{U}}^2$ ,  $\Delta B_q^\nu(Q^2)/c_{V\mathcal{U}}^2$ ,  $\Delta C_q^\nu(Q^2)/c_{V\mathcal{U}}^2$  and  $\Delta D_q^\nu(Q^2)/c_{V\mathcal{U}}^2$  induced by the unparticle in this case are as follows:

$$\begin{aligned}
2\Delta B_q^\ell(Q^2)/c_{V\mathcal{U}}^2 &\approx \Delta C_q^\ell(Q^2)/c_{V\mathcal{U}}^2 \approx -\frac{Q_q}{4\pi\alpha M_Z^{2(d_{\mathcal{U}}-1)}} \frac{A_{d_{\mathcal{U}}}}{\sin(d_{\mathcal{U}}\pi)} (Q^2)^{(d_{\mathcal{U}}-1)} \\
&\quad + \frac{V_q V_\ell}{16\pi\alpha \sin^2 \theta_W \cos^2 \theta_W M_Z^{2(d_{\mathcal{U}}-1)}} \frac{A_{d_{\mathcal{U}}}}{\sin(d_{\mathcal{U}}\pi)} \frac{(Q^2)^{d_{\mathcal{U}}}}{Q^2 + M_Z^2} \\
\Delta D_q^\ell(Q^2)/c_{V\mathcal{U}}^2 &\approx \frac{A_q A_\ell}{16\pi\alpha \sin^2 \theta_W \cos^2 \theta_W M_Z^{2(d_{\mathcal{U}}-1)}} \frac{A_{d_{\mathcal{U}}}}{\sin(d_{\mathcal{U}}\pi)} \frac{(Q^2)^{d_{\mathcal{U}}}}{Q^2 + M_Z^2} \\
2\Delta B_q^\nu(Q^2)/c_{V\mathcal{U}}^2 &\approx \Delta C_q^\nu(Q^2)/c_{V\mathcal{U}}^2 \approx \frac{V_q}{\sqrt{2} M_Z^{2d_{\mathcal{U}}}} \frac{A_{d_{\mathcal{U}}}}{G_F \sin(d_{\mathcal{U}}\pi)} (Q^2)^{(d_{\mathcal{U}}-2)} (Q^2 + M_Z^2) \\
\Delta D_q^\nu(Q^2)/c_{V\mathcal{U}}^2 &\approx \frac{A_q}{V_q} (\Delta C_q^\nu(Q^2)/c_{V\mathcal{U}}^2)
\end{aligned} \tag{23}$$

From the above equations, we can see that  $\Delta B_q^\ell(Q^2)$ ,  $\Delta C_q^\ell(Q^2)$ ,  $\Delta D_q^\ell(Q^2)$ ,  $\Delta B_q^\nu(Q^2)$ ,  $\Delta C_q^\nu(Q^2)$  and  $\Delta D_q^\nu(Q^2)$  in the pure vector unparticle coupling case are closely related to those in the pure axial vector coupling case. Thus, we can learn how  $\Delta C_u^e(Q^2)/c_{V\mathcal{U}}^2$ ,  $\Delta D_u^e(Q^2)/c_{V\mathcal{U}}^2$  and  $\Delta C_u^\nu(Q^2)/c_{V\mathcal{U}}^2$  vary with respect to  $Q^2$  in the pure vector coupling case by making some replacements in Fig.2-Fig.4.

### III. ASYMMETRIES IN DEEP INELASTIC POLARIZED ELECTRON NUCLEON SCATTERING AND UNPARTICLE

There is a strong belief in the physics community that the Standard Model of particles and interactions is incomplete. Much effort has been paid to search for new physics, and will continue to do so in the upgraded Tevatron, the LHC, and the future Linear Collider(ILC). Direct searches are complemented by precision electro-weak experiments that search for the indirect effects of new physics by comparison with expectations calculable in the Standard Model. Parity violation as an important indirect search for new physics provides precise

measurement of electroweak couplings at low  $Q^2$ . This measurement is complementary to other existing or planned precision measurement, then yields strong constraints on the possible deviations from the Standard Model predictions and distinguish various new physics. The Jefferson laboratory has planed to measure precisely the parity violating asymmetry in DIS[7].

The general four fermion lagrangian takes the following form[8], which is responsible for the new physics contribution to the parity violation DIS asymmetry,

$$\mathcal{L}_{PV} = \frac{4\pi\kappa^2}{\Lambda^2} \sum_{q,i,j} h_{ij}^q \bar{e}_i \gamma_\mu e_i \bar{q}_j \gamma^\mu q_j \quad (24)$$

where  $\kappa$  is the coupling strength of the new interaction,  $\Lambda$  is the characteristic mass of the new degree of freedom, and the  $h_{ij}^q$  are the helicity-dependent coupling parameters of the quark  $q$  with  $i$  and  $j$  denoting the handedness of the given fermion. From the effective interaction Eq.(3) between unparticle and the SM field, we learn that the virtual exchange of unparticle can result in the following four fermion interaction relevant to the parity violating DIS asymmetry.

$$\begin{aligned} \mathcal{L}_{PV}^{\mathcal{U}} = & \frac{A_{d\mathcal{U}}}{2 \sin(d_{\mathcal{U}}\pi)} \frac{1}{Q^2} \left(\frac{Q^2}{M_Z^2}\right)^{d_{\mathcal{U}}-1} \sum_q [c_{RU}^2 \bar{e} \gamma_\mu P_R e \bar{q} \gamma^\mu P_R q + c_{RU} c_{LU} \bar{e} \gamma_\mu P_R e \bar{q} \gamma^\mu P_L q \\ & + c_{RU} c_{LU} \bar{e} \gamma_\mu P_L e \bar{q} \gamma^\mu P_R q + c_{LU}^2 \bar{e} \gamma_\mu P_L e \bar{q} \gamma^\mu P_L q] \end{aligned} \quad (25)$$

here  $P_R$  and  $P_L$  are the usual projection operator  $P_{R,L} = \frac{1}{2}(1 \pm \gamma_5)$ ,  $c_{RU}$  and  $c_{LU}$  are expressed in terms of the vector and axial vector coupling constants  $c_{V\mathcal{U}}$ ,  $c_{A\mathcal{U}}$ ,

$$\begin{aligned} c_{RU} &= c_{V\mathcal{U}} + c_{A\mathcal{U}} \\ c_{LU} &= c_{V\mathcal{U}} - c_{A\mathcal{U}} \end{aligned} \quad (26)$$

For a isosinglet target such as the deuteron, the assumption of isospin symmetry is generally made (i.e., all u and d distributions interchanged for the proton and neutron). At sufficiently high  $x$ , the relative importance of sea quark contributions approaches zero. And then the parity asymmetry  $A_{ed}(x, y)$  is insensitive to parton distribution functions. To the leading order of  $Q^2/M_Z^2$ , after length calculation, we have

$$\begin{aligned} A_{ed}(x, y) = & \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = -\frac{G_F Q^2}{2\sqrt{2}\pi\alpha} \frac{9}{10} \left\{ \left[ 1 - \frac{20}{9} \sin^2 \theta_W + \frac{1}{3} \xi(Q^2) c_{V\mathcal{U}} c_{A\mathcal{U}} \right] + \left[ 1 - 4 \sin^2 \theta_W + \right. \right. \\ & \left. \left. \frac{1}{3} \xi(Q^2) c_{V\mathcal{U}} c_{A\mathcal{U}} \right] \frac{1 - (1-y)^2}{1 + (1-y)^2} \right\} \end{aligned} \quad (27)$$



where  $\xi(Q^2) = \frac{\sqrt{2}A_{d_U}}{\sin(d_U\pi)} \frac{1}{Q^2 G_F} (\frac{Q^2}{M_Z^2})^{d_U-1}$ , if we set  $c_{VU} = c_{AU} = 0$ , the above asymmetry factor  $A_{ed}(x, y)$  reduces to the well-known results in SM[8]. As an illustration, the predicted asymmetries in deep inelastic electron-deuteron scattering are shown in Fig.5 for  $Q^2 = 10\text{GeV}^2$  and with different scale dimensions of unparticle. From this figure, we can see that the asymmetry  $A_{ed}$  is very sensitive to the scale dimension  $d_U$ : if  $1.5 < d_U < 2$  we almost can not distinguish the SM from the new physics with unparticle, however when  $1 < d_U < 1.5$ , the situation is changed drastically, i.e., the differences between  $A_{ed}$  due to unparticle and one of SM become rather large. Consequently, by this result, the future precision measurement of  $A_{ed}$  would impose a strong constrain to  $d_U$ .

For the sake of completeness we now indicate the result for a proton target, rather than give qualitative results for all x and y, we have chosen  $x = \frac{1}{3}$  to give quantitative predictions. Here the "valence" quarks dominate, and furthermore for the proton  $u(x = \frac{1}{3}) \approx d(x = \frac{1}{3})$ , as in the most naive quark-parton model. Then we find the parity asymmetry  $A_{ep}(x = \frac{1}{3}, y)$  in deep inelastic electron-proton scattering,

$$A_{ep}(x = \frac{1}{3}, y) = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = -\frac{G_F Q^2}{2\sqrt{2}\pi\alpha} \left\{ \left[ \frac{5}{6} - 2\sin^2\theta_W + \frac{1}{2}\xi(Q^2) c_{VU}c_{AU} \right] + \left[ \frac{5}{6}(1 - 4\sin^2\theta_W) + \frac{1}{2}\xi(Q^2) c_{VU}c_{AU} \right] \frac{1 - (1 - y)^2}{1 + (1 - y)^2} \right\} \quad (28)$$

The above parity asymmetry  $A_{ep}(x = \frac{1}{3}, y)$  becomes the standard result in SM in the case of  $c_{VU} = c_{AU} = 0$ [8]. The asymmetry predicted in SM and new physics with unparticle is shown in Fig.6 for longitudinally polarized electron-proton deep inelastic scattering. Similar to the electron-deuteron case, it is always negative, and the asymmetry  $A_{ep}(x = \frac{1}{3}, y)$  in SM almost coincide with that in the unparticle scenario for  $1.5 < d_U < 2$ , but not as large (in magnitude) as for the electron-deuteron case.

In Fig. 5 and 6, in order to show the  $A_{ep}(x = \frac{1}{3}, y)$  curves explicitly and concretely, we have taken  $c_{VU} = c_{AU} = 0.01$ . The values of  $c_{VU}$  and  $c_{AU}$  reflect the strength of coupling between SM-operators and the unparticle's. Since the new physics corrections to SM due to unparticle must be rather small, we have  $|c_{VU}| \sim |c_{AU}| \ll 1$ . When  $c_{VU} = c_{AU} = 0.01$  is assumed, the corrections to  $A_{ep}(x = \frac{1}{3}, y)$  are proportional to order of  $\mathcal{O}(c_{VU}c_{AU}) \sim 10^{-4}$ .

## IV. CONCLUSION

Unparticle stuff with nontrivial scale invariance may exist in our world, and there are a lot of rich phenomenologies associated with the unparticle, such as the unparticle physics effects in fragmentation functions and its contribution to the NuTeV anomaly *etc*[9], which can serve as the experimental tests of the unparticle. In this paper, we have demonstrated the unparticle effects in the neutral current exchange DIS processes  $\ell(\nu)N \rightarrow \ell(\nu)X$  and the parity violation asymmetry in electron nucleon deep inelastic scattering in the framework of the effective theory.

Low energy experiment is uniquely sensitive to new physics, which is complementary to direct new physics searches and very useful to distinguish various new physics pictures. If there is really a scale invariant sector, it would manifest itself not only in parity violation asymmetry in electron-nucleon deep inelastic scattering, but also in parity violation Möller scattering, atomic parity violation, parity violation electron-proton scattering *etc* low energy measurements. Parity violating asymmetry in DIS is investigated in this work, together with precise measurement of other low energy observables (such as the QWeak experiment at JLab), they will yield strong constraints on the unparticle parameter, and will play important role in distinguish the unparticle scenario from other extensions of the SM (such as supersymmetry, leptoquarks and so on).

## ACKNOWLEDGEMENTS

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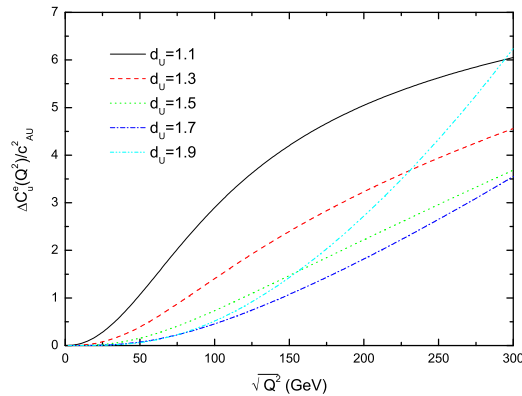


FIG. 2: The unparticle correction to  $C_u^e(Q^2)$  in unit of  $c_{AU}^2$  for  $d_U = 1.1, 1.3, 1.5, 1.7, 1.9$  in the  $c_{VU} = 0$  and  $c_{AU} \neq 0$  case

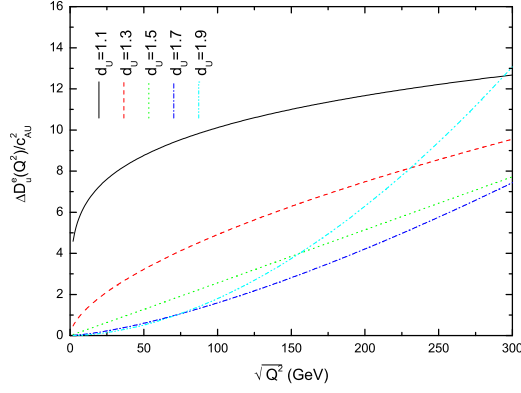


FIG. 3: The unparticle correction to  $D_u^e(Q^2)$  in unit of  $c_{AU}^2$  for  $d_U = 1.1, 1.3, 1.5, 1.7, 1.9$  in the  $c_{VU} = 0$  and  $c_{AU} \neq 0$  case

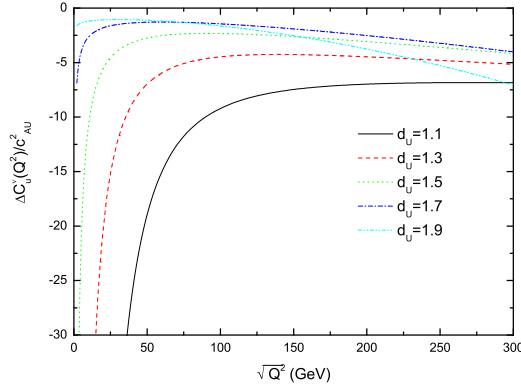


FIG. 4: The unparticle correction to  $C_u^\nu(Q^2)$  in unit of  $c_{AU}^2$  for  $d_U = 1.1, 1.3, 1.5, 1.7, 1.9$  in the  $c_{VU} = 0$  and  $c_{AU} \neq 0$  case

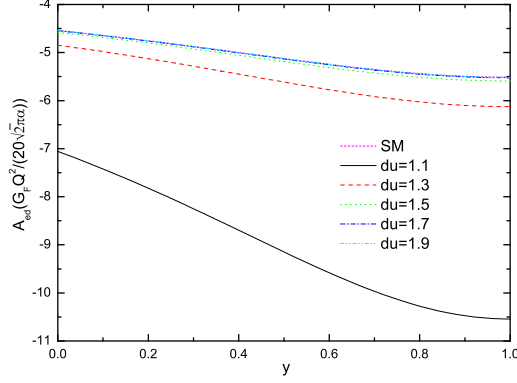


FIG. 5: The asymmetry  $A_{ed} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$  for the deep inelastic polarized electron deuteron scattering as a function of  $y = (E - E')/E$  in SM and the new physics scenario with unparticle for  $d_U = 1.1, 1.3, 1.5, 1.7, 1.9$ . The asymmetry is given in unit of  $\frac{G_F Q^2}{20\sqrt{2}\pi\alpha}$ , here we assume  $Q^2 = 10\text{GeV}^2$ ,  $c_{VU} = c_{AU} = 0.01$ .

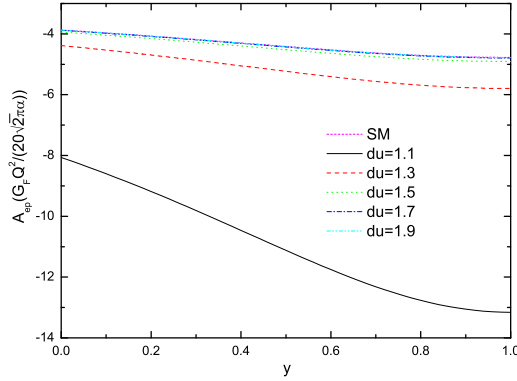


FIG. 6: The asymmetry  $A_{ep}(x = \frac{1}{3}, y) = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$  for the deep inelastic polarized electron-proton scattering as a function of  $y = (E - E')/E$  in SM and the new physics scenario with unparticle for  $d_U = 1.1, 1.3, 1.5, 1.7, 1.9$ . The asymmetry is given in unit of  $\frac{G_F Q^2}{20\sqrt{2}\pi\alpha}$ , and we assume  $Q^2 = 10\text{GeV}^2$ ,  $c_{VU} = c_{AU} = 0.01$  as in Fig.5 for the electron-deuteron case.